

Design and fabrication of a dietary bitter leaf processing machine

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ABSTRACT

Bitter leaf (*vernonia amygdalina*) soup is a major delicacy in most parts of Africa and beyond. The methodical processing of the leaf into an acceptable form during cooking poses a big challenge to its mechanization. This paper, hence, focused on the design and development of manual-operated bitter leaf processing equipment for straining, tearing and washing off the bitter content of bitter leaf, used in soup and sauce preparations. The developed machine has an overall dimension of 420 x 330 x 1045 mm. The main components of the machine include the hopper, the crank mechanism, the digester chamber and the support frame. The components were majorly made of steel materials. Two annuli of length 130 mm and diameter 38 mm were designed and cut. Five 120 mm x 10 mm rod beaters each were staggered welded onto the outer surface to form a gear-like. The annuli were force-fitted on two 15 mm diameter shafts and then held in mesh within the chamber; mounted using anti-friction bearings. As the machine is cranked, the digester mesh engulfs the feed bitter leaf from the hopper, squeeze, strain and press out the bitter green foamy liquid, which is washed out with the help of water. It takes an average of 5 minutes to fully process a batch of 0.4 kg of bitter leaf. The equipment processes bitter leaf into the acceptable mixture sizes of between 5 – 40 mm at a rate up to ten times faster, compared to the hand method.

Keywords: bitter leaf, dietary form, processing, machine design, beater shaft

1. INTRODUCTION

Processing agricultural produce into acceptable forms for consumption is an important aspect of the economic food value chain. A well-prepared dish makes it worth salivating. Bitter leaf (*Vernonia amygdalina*) soup is a major delicacy in most parts of the world, especially in Africa, Asia and Latin America. Bitter leaf is a sustainable perennial shrub that can be found fresh growing wild or cultivated, both in the rainy and dry seasons. It is highly resilient to harsh weather and soil conditions. It is native to most African countries where it is used in dietary and medicinal activity among others (Huffman, 1989; Malav et al., 2020). While the washed leaf is consumed as food, the juice extract finds applications in many other areas. Bitter leaf extract which, relatively, has received more attention in the literature is identified to



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treat many human and animal ailments such as malaria, cancer and stomach upsets. The dried leave is ground and the juice is extracted through various solvent extraction methods (Dinh et al., 2019; Tunasamya et al., 2019). Histological studies reveal that bitter leaf extract boosts the immune system both in humans and animals due to its antioxidant and prebiotic effects, and vitamin content (Ezeonu and Ukwu, 2009; Ajayi, 2018; Akpor et al., 2021). Achuba (2018) evaluated and concluded that bitter leaf extract has a reversible toxicity effect on renal dysfunction caused by crude petroleum ingestion. It has also been used in the treatment of insect infestations (Ugbogu et al., 2021). Edegbai and Anoliefo (2019) indicated that the bitter leaf plant serves as a hedge, a source of firewood, and is also used as a chewing stick. Aisida et al., (2019) claim to have produced an anti-bacterial drug through the biosynthesis of silver nanoparticles and dried bitter leaf extract. Abdulwahab et al., (2019) studied the use of non-toxic bitter leaf extract as an anti-corrosion inhibitor in Ti-6Al-4V alloy used as a biomedical dental implant. The positive potential was attributed to the formation of a thin film over the Titanium alloy due to the functional group electron pairs and the tannin saponin content of the bitter leaf.

The conventional but itinerant processing methods of bitter leaf for making soup/sauce and its extracts for other purposes remain part of the most demanding, labour-intensive, post-harvest tasks. It is an arduous and unhygienic activity that lacks standards and is carried out by peasants. The amount of beneficial contents retained in the processed bitter leaf for soup preparation depends on the technique. Agomuo et al., (2016) studied the effect of the traditional hand squeeze-washing of the bitter leaf on the nutritional content and observed that both the nutritional and the anti-nutritional content were reduced. The result corroborates the findings of Yakubu et al., (2012) that studied the effects of four processing methods, soaking in water, blanching, abrasion with salt and without salt and observed that the abrasion without salt technique performed best in terms of removing the antinutrients and retaining of the essential nutrients. It was argued that the drastic reduction of the phytochemicals makes the bitter leaf safe for human consumption. Garba and Oviosa, (2019) studied the effects of different drying methods, air, sun, oven and solar dryings on the nutritional content of dried bitter leaf. It was observed that the concentration of both the organic and mineral constituents increased with oven and solar drying.

In the southern part of Nigeria, bitter leaf is processed essentially for food. The bitter leaves are harvested from the farm or in rare cases procured from the market by the processor and put under the sun for about 10 minutes to reduce moisture and toughen the leaves. This would make the leaves not disintegrate excessively into particulates during the hand washing process that followed. The washing reduces the bitterness to an acceptable level as well as macerating the leaves. The washing and macerating process are stopped when the acceptable bitterness level is reached. The time to stop is determined by the processor who conducts organoleptic tests at time intervals through taste. The sizes of the washed bitter leaf pieces normally range between 5 to 40 mm. Most of the mechanization in the processing of bitter leaves has been in the area of juice extraction for non-food purposes. Adetunji et al. (2018), as well as Oke et al., (2015), developed bitter leaf juice extractors using a modified screw conveyor that presses out the liquid from the macerated leaves. The tapered conveyor has a kink at the discharge end that enabled it to spike the pressure necessary for expelling the juice from the leaves. While the juice was regarded as a product mainly used for medicinal purposes, the crushed leaf mash was regarded as waste residue with no consideration for its form. Adeyeri et al., (2018) carried out a theoretical design and evaluation of a dry vegetable pulverizing and packaging machine. The design simulation has a pulveriser section that uses a hammer mill to crush the dried leaves while the packaging section operates using the belt conveyor system. Tangka (2006) developed a vegetable pulper for green leaves. The leaves were chopped using two knives mounted on a rotating shaft inside the hopper. The machine cuts the leaves but has no mechanism for washing and pressing out the bitter liquid from them which is the main requirement in the processing of vegetable bitter leaf for food. However, Tangka and Penda, (2007) developed an upgraded version of the pulper, specifically for bitter leaf processing, by incorporating a washing section and also a spinning dewatering section. It was, however, noted that the machine chopped the leaves into very small sizes (2.64 mm) which is an unacceptable form for making soup, especially within the Southeast of Nigeria, where the bitter leaf is not necessarily chopped. Hence, due to the near absence of appropriate machines for processing bitter leaves into suitable forms for soup preparations, this study has focused on developing a hand-cranked bitter leaf processing machine suitable for both rural and urban dwellers. The target machine is such that will reduce the incidence of poorly washed leaves while avoiding excessive crushing. The developed machine mimics the hand-process method, and reduces the bitter content of the leaf appreciably with moderate maceration, to achieve the desired texture form.

2. METHODOLOGY

Design considerations

Considerations were made on the required quantity of bitter leaf to be processed per batch and that could be handled manually during the development of the bitter leaf processing machine. The physical properties of the input, bitter leaf (shape, bulk density (equals 400 kg.m^{-3}), moisture content), and the desired texture form of the output product were considered to ensure a reduction in the bitter content at an acceptable level of maceration. Bitter leaf has a pH of between 3 – 6. The absence of power supply in many rural areas and the epileptic supply in urban settings of some developing economies like Nigeria; the continuously increasing cost of fuelling generators and the high initial cost of installing solar energy systems, informed the choice of a hand-cranked design. A one-man operator was considered to be ideal for handling and operation. It has to be portable so that it can be moved to point of need and convenience taking cognisance of the fact that commercial hand processors relocate to the streams because of water supply. The operation has to be simple with little maintenance compared to motorized machines having similar operations. The processing of the leaves requires an adequate supply of water in addition to the water content of the leaves, therefore materials with corrosion resistance were considered. However, to minimize cost coupled with availability, treated carbon steel was considered. Non-contacting parts and parts with no relative motion were to be painted to avoid excessive corrosion. It was also noted (Abdulwahab et al., 2019) that bitter leaf extract acts as a natural corrosion inhibitor.

Materials

Materials used include galvanized steel sheets for the hopper to avoid corrosion, and contamination and also for durability. Medium carbon steel rods were used for the shafts and the meshing element of the digester because of the needed strength to withstand torsional and bending stresses while taking in the cost factor. The sump and the basin were made of galvanized steel sheets. The support frame was made of angle iron and then coated to protect it from corrosion. Roller bearings were used to mount the driving and the driven digester shafts. Bolts, nuts, and hinges were used as fasteners for easy maintenance product removal.

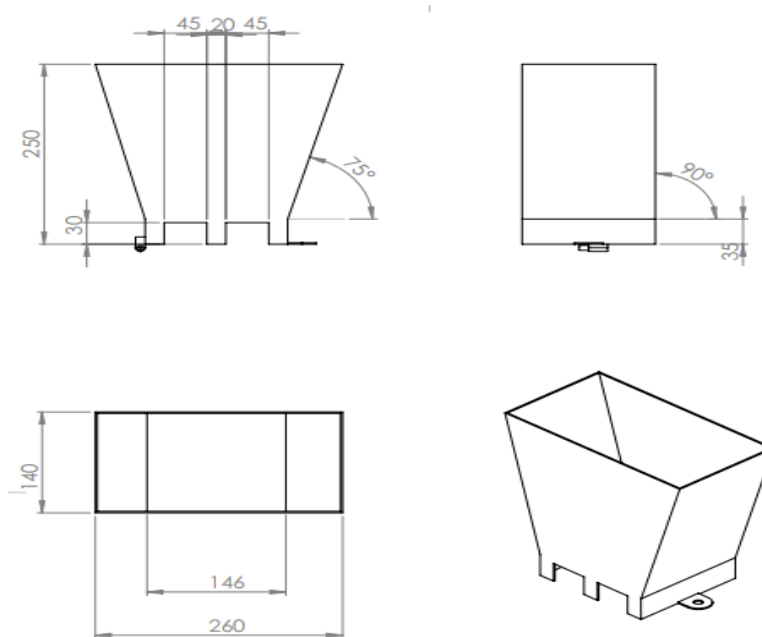


Figure 1 Orthographic and Isometric views of the Hopper

Method

The concept design sketches were done on paper before the modelling processes. The design tool used to model the prototype is SolidWorks 2016. Dimensioned views of individual components and assembly drawings were executed. Calculations were done to ascertain its functionality and ruggedness before the various activities of the fabrication in the workshop, followed by functionality tests.

Hopper: The hopper is positioned at the maximum ergonomic height and provides the inlet for feeding the bitter leaf into the digester. It is made of a cut and welded galvanized steel sheet. The hopper in combination with the bottom shell hinged on it

houses the digester unit. It is required that the angle of inclination of the hopper must be greater than the repose angle of the vegetable mixture by at least 15° to ensure the positive flow of vegetable mixture within the hopper; angles of 75° and 90° were chosen for the design. A trapezoidal 6-litre capacity hopper was fabricated.

Given the hopper dimensions (see Fig. 1), length, $l = 136$ mm, height, $h = 215$ mm, base width, $b = 146$ mm, and top width, $t = 256$ mm.

The hopper shape is similar to that of a trapezoidal frustum, its volume, V_H is given by:

$$V_H = l \times h \times (b + t)/2 = 136 \times 215 \times (146 + 256)/2 = 5877240 \text{ mm}^3 \approx 0.006 \text{ m}^3$$

Shafts: Three shafts of different sizes (see Fig. 2) were machined on a lathe. The $\phi 10$ mm digester elements, 5 each, were welded unto the $\phi 38$ mm cylindrical surface of the two stepped shafts and driven spur gears mounted at their crank end. The two shafts were juxtaposed to create a mesh of the digester beaters. The crank handle is attached to the third shaft which carries the driving spur gear used as the speed multiplier that transmits torque to the digester unit. Three cast iron spur gears have pitch circle diameters of 140 mm for the driving gear and 60 mm for the two equal driven gears and have a counted number of teeth of 44 and 18 respectively. The positioning of the handle on the right side ensures ergonomic convenience and the inward rotation of the two digester shafts, hence trapping the bitter leaves. Each of the shafts was supported on two bearings attached to the frame. Roller bearings would have been best suited for this machine as their properties help reduce noise. However, single-row deep groove ball bearings were used, being the most common type of ball bearings available in different sizes. It bears the shaft's radial and thrust loads. Standard radial ball bearing, 33-15 AFBMA 20.1 with an outer diameter of 42 mm, a thickness of 19 mm and a bore of $\phi 15$ mm, having eight balls was selected.

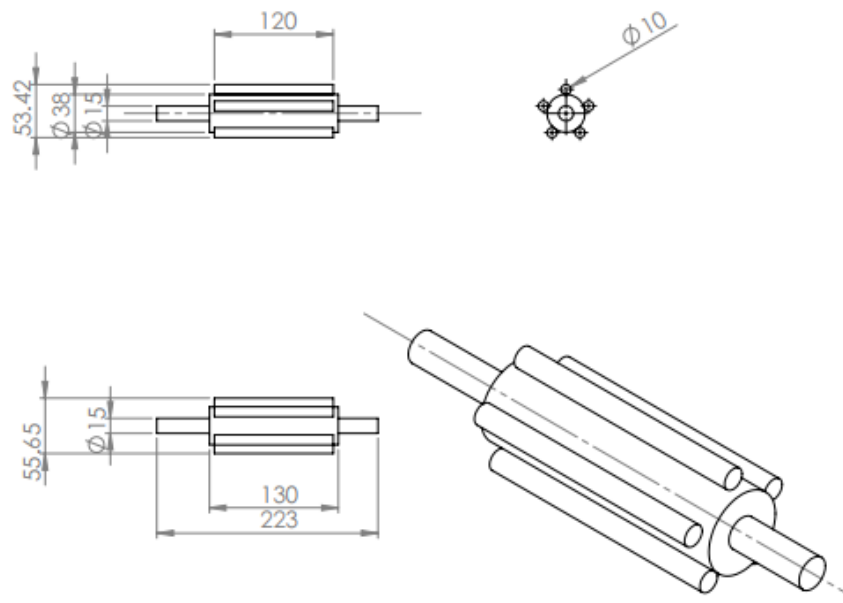


Figure 2 Orthographic and Isometric views of the digester beaters

Sump (Bottom shell): The bottom shell is a W-shaped part that covers the bottom part of the digester unit. A galvanized steel sheet was rolled to size and cut sections welded to obtain the sump as shown in Fig. 3. It is attached to the downside of the hopper using hinges, bolt and nut. During operation, it is latched to the hopper using a bolt and nut, giving a part-clearance of about 5 mm from the sides of the hopper. It opens downwards to enable product discharge.

Basin: The basin receives the mixture of digested bitter leaf and water when the bottom shell is opened after washing. The triangular trough is made of galvanized steel sheets cut to sizes and welded together into shape (see Fig. 4). It slopes downwards on one side such that the vegetable is retained in the trough as the liquid drains away through the screen of the exit pipe.

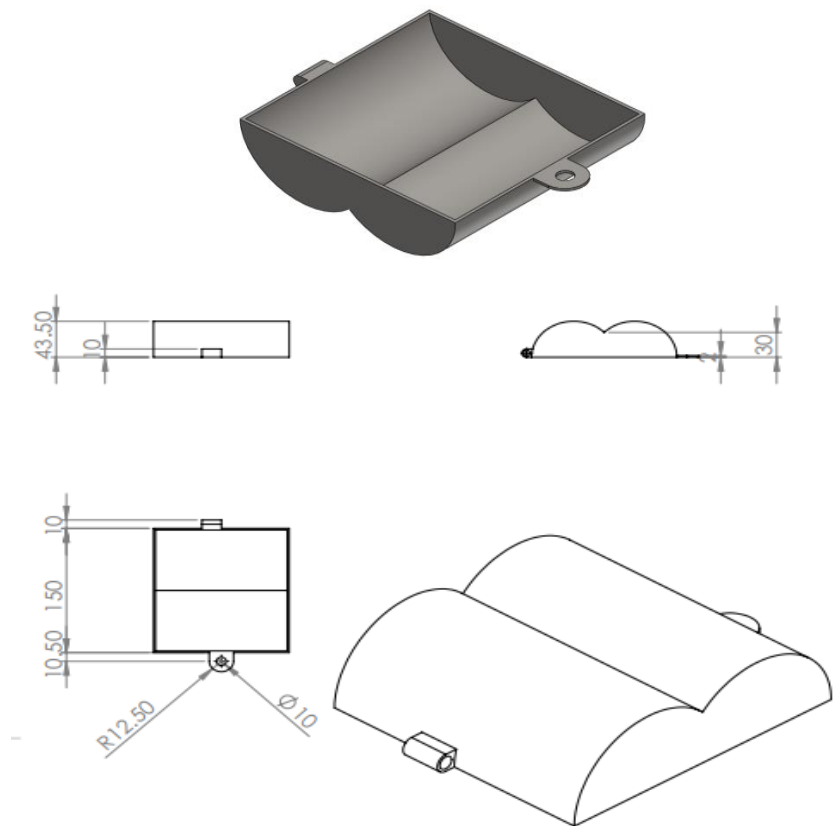


Figure 3 Orthographic and Isometric views and rendering of the Bottom shell, sump

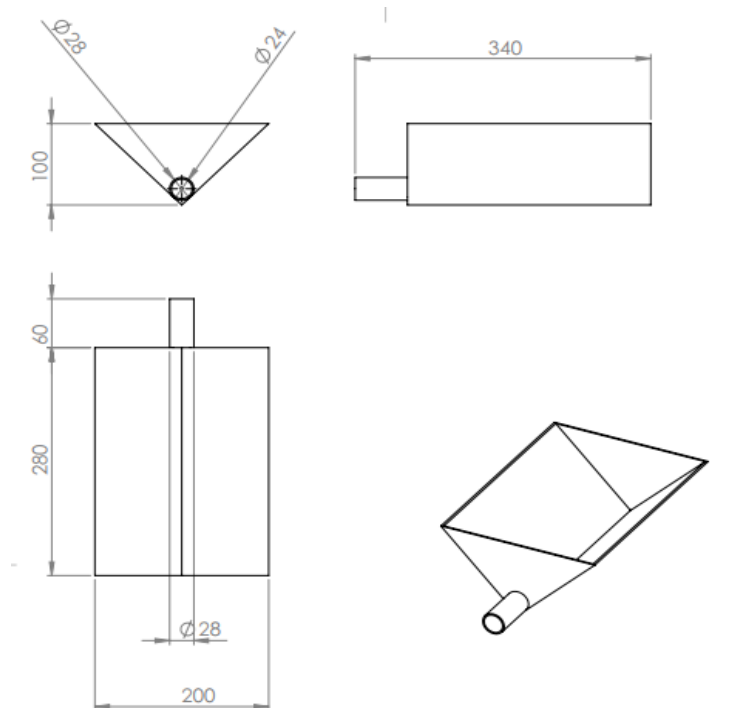


Figure 4 Orthographic and Isometric views of the collection Basin

Frame: The frame provides support for the machine units with good ground clearance. It was fabricated from a 35 x 35 x 3 mm angle iron. The angle iron was cut to sizes and welded together to form a stand of 360 x 280 x 795 mm structure as shown in Fig. 5. The structure took into consideration an average operator height to ensure ergonomic convenience (see Fig. 6).

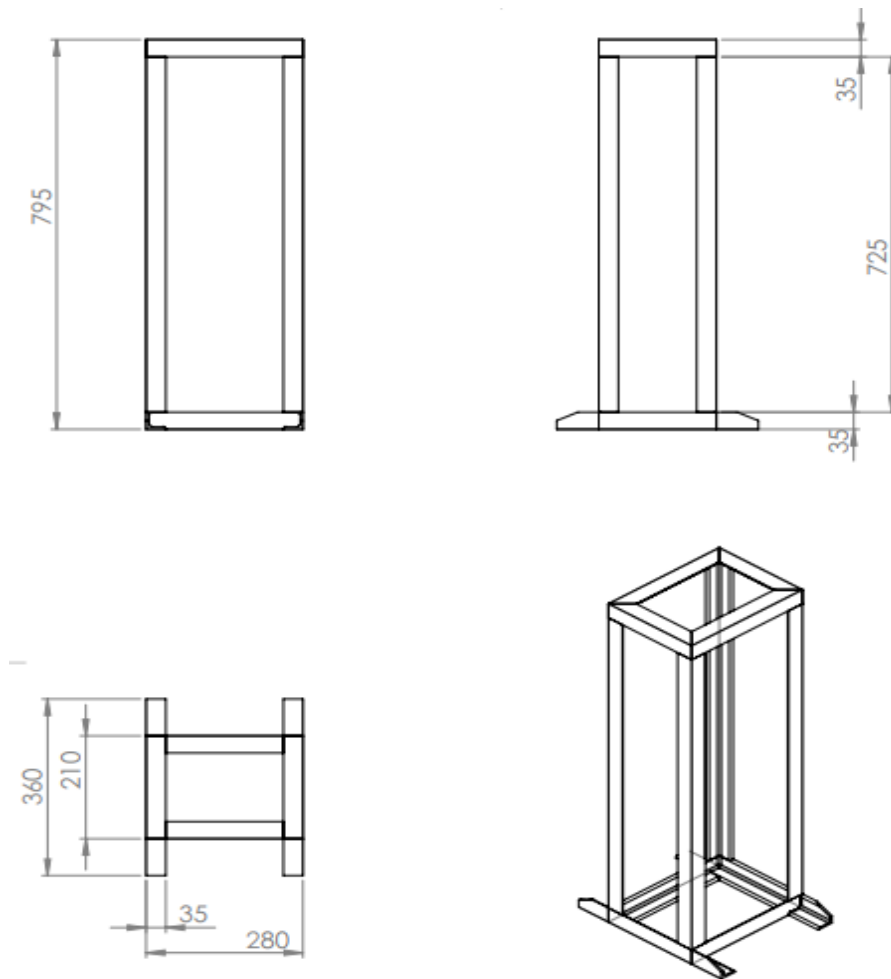


Figure 5 Orthographic and Isometric views of the Frame

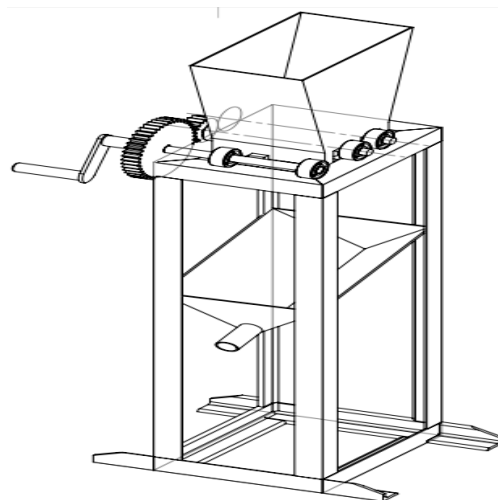


Figure 6 Isometric view of the bitter leaf machine

3. RESULTS ANALYSIS AND DISCUSSION

The designed and fabricated bitter leaf processing machine (see Fig. 7.) has overall dimensions of 420 x 330 x 1045 mm. It was produced using locally available materials listed as shown in Table 1. The machine was checked to ensure completeness in the assembling and then operated to evaluate its functionality.

Principle of operation:

The partially sunned bitter leaf is loaded through the hopper. The leaves under gravity and aided by a gentle press go into the digestion chamber where the digester engulfs the leaves through the counter-rotational movement of the two meshed digester beaters. The juxtaposed shafts carrying the beaters receive motion through the hand-cranking action from the handle. The three-gear system train, driver, first driven and the second driven gears ensure that appropriate input torque and speed ratios were applied. The rotating beaters press, macerate and strain the leaves, thereby exposing the cells for subsequent removal of the bitter liquid in the leaves. Enough water is added through the hopper to properly wash off the foamy bitter liquid. Organoleptic tests through taste are done to ascertain the quality at which to end a batch process. Trial runs carried out showed that the machine performed optimally.

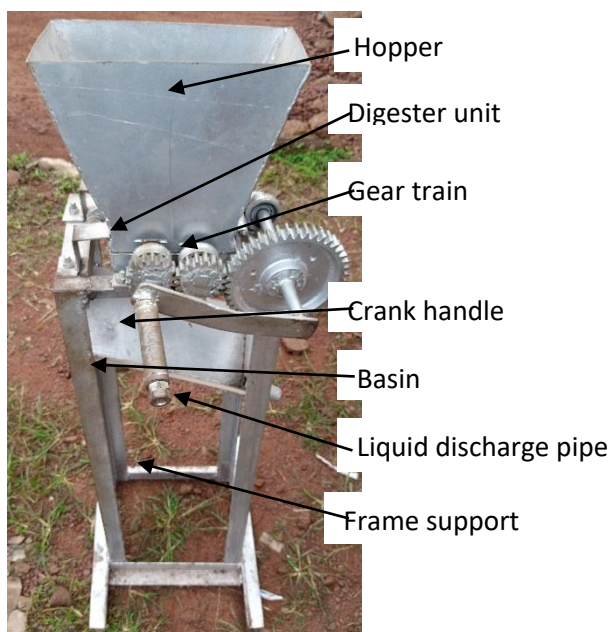


Figure 7 Fabricated bitter leaf processing machine

Table 1 Summary of the material selection process

| S/N | Quantity | Part | Requirement | Choice | Reason |
|-----|----------|-------------------|--|---|---------------------------------------|
| 1 | 1 | Hopper | Corrosion resistance | Galvanized steel sheet | Low cost, Available |
| 2 | 2 | Digester unit | Corrosion/Wear resistance | Medium carbon steel with heat treatment | Relatively Low cost, Reduced reaction |
| 3 | 1 | Sump | Corrosion resistance | Galvanized steel sheet | Low cost, Available |
| 4 | 1 | Basin | Corrosion resistance | Galvanized steel sheet | Low cost, Available |
| 5 | 3 | Gear train, gears | Hardness, Strength and wear resistance | Cast iron | Available |

| | | | | | |
|---|---|---------------|---------------------------|------------------------|---------------------|
| 6 | 6 | Ball bearings | Hardness, Wear resistance | AFBMA standard bearing | Available |
| 7 | 1 | Frame | Strength, | Angle bar (iron) | Low cost, Available |

Based on preliminary measurements, the following bending and shear stress analyses were done on the critical component, the digester, for a batch feed of 0.4 kg of bitter leaf and 1.5 litres of water. From the attached gear weight of 0.5 kg, one digester shaft with the beater weight of 1 kg and the digester self-weight and the feed assumed to be distributed over the portion of the digester shaft as shown in *Fig. 8*, then the shear force diagram in *Fig. 9* was obtained.

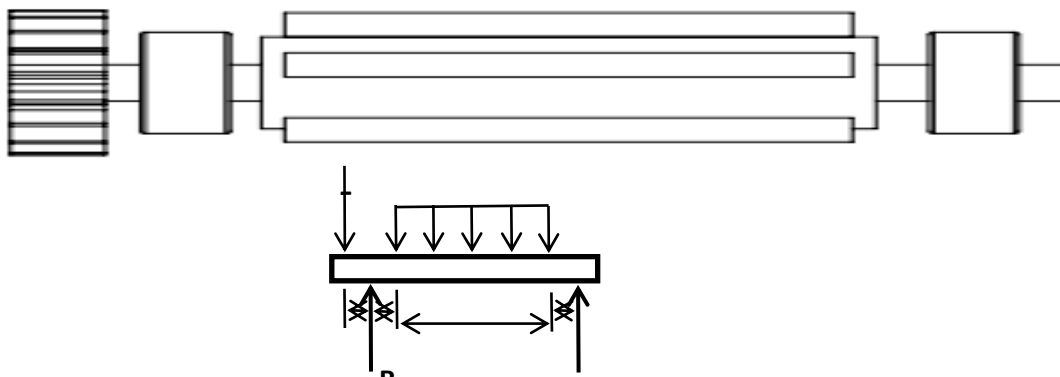


Figure 8 Freebody diagram of the digester shaft

Given the acceleration due to gravity, g , as 9.81m^2 , gear vertical force, $F_G = 4.905\text{N}$ and distributed load, $F_{DL} = 19.13\text{N}$. Summing vertical forces, the reactions at points B and E give, $R_B = 6.923\text{N}$ and $R_E = 0.4689\text{N}$ respectively. The calculated shear forces are: $(SF)_A = -4.905\text{N}$, $(SF)_B = 2.018\text{N}$, $(SF)_C = 2.018\text{N}$, $(SF)_D = -0.4689\text{N}$ and $(SF)_{D-E} = -0.4689\text{N}$. This gives maximum shear stress of $27,746\text{Nm}^{-2}$ (0.028MPa) between points A and B, which is far below the shear strength of ordinary carbon steel ($260 - 320\text{MPa}$). The applied shear stress is therefore too low to warrant further analysis as failure is ruled out.

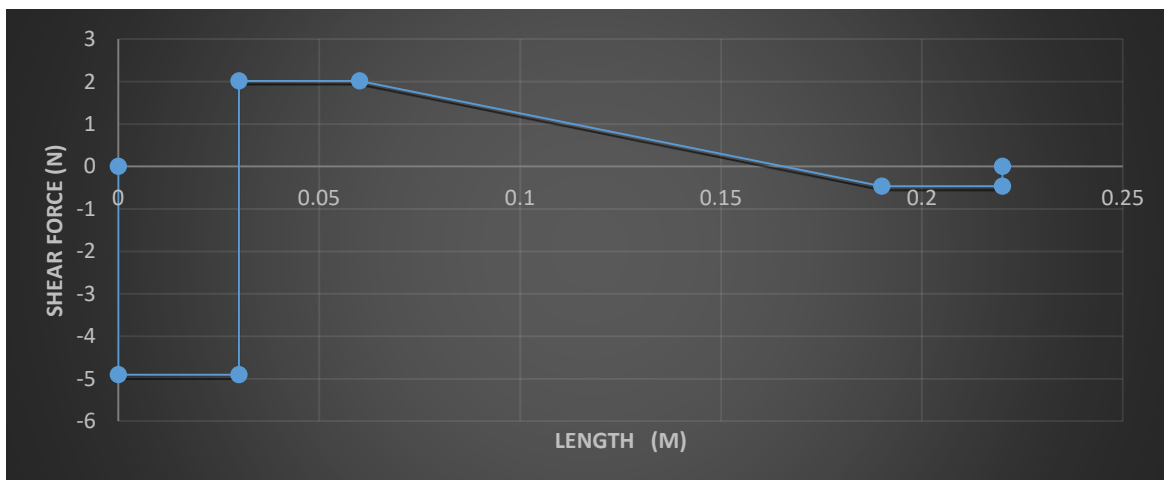


Figure 9 Shear force diagram of the digester shaft

The following value were calculated for the bending moment of the digester shaft: $(BM)_A = 0\text{Nm}$, $(BM)_B = -0.1472\text{Nm}$, $(BM)_C = -0.0866\text{Nm}$, $(BM)_D = 0.01408\text{Nm}$ and $(BM)_E = 0\text{Nm}$. The maximum bending moment is calculated at point B, therefore the maximum bending stress will also occur at this point.

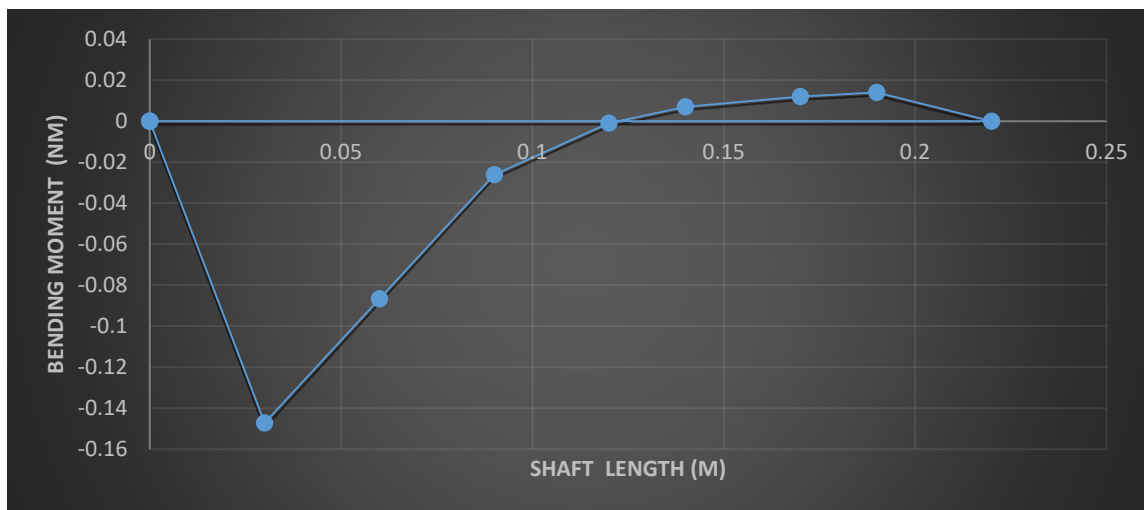


Figure 10 Bending moment diagram of the digester shaft

The maximum bending stress $\sigma_b = M/Z$, where $Z = I/C$ is the section modulus. Given: $I = \pi d^4/64$ and $C = d/2$, with $d = 0.015$ m. Substituting the values in the formulae gave the applied stress as 0.444 MPa. The bending strength of steel is above 370 MPa, therefore the applied stress is not likely to cause failure in bending.

Because the human effort is highly variable and stochastic, the maximum torque to failure will be calculated. Given tensile strength to be 315 MPa, the torsional strength is obtained as 75% of tensile strength, which equals $0.75 \times 315 \text{ MPa} = 236 \text{ MPa}$. The maximum torque to failure $T_{\max} = \tau J/r = \pi d^3 \tau / 16$. After substituting for the torsional strength and shaft diameter, $d = 0.015$ m, the maximum torque is obtained as 156 Nm. This torque is not likely to be reached given that the vegetable offers very little resistance especially when water is added. Hence the machine remained rugged and safe.

4. CONCLUSION

The concern of this study was the design and fabrication of a bitter leaf processing machine that will macerate the leaves and wash off the bitter content without disintegrating the leaves excessively. The fabricated machine has overall dimensions of 420 x 330 x 1045 mm and is adaptable to the local product requirement. It took an average of 5 minutes to fully process a batch of 0.4 kg of bitter leaf feed into the machine. All welded joints, fasteners, moving parts and mechanisms were checked before and after the test run and were found intact. The gears and the digester were also in perfect sync mesh and maintaining alignment. The processed leaves were also tested by the local people and found to be acceptable both in texture and taste as a considerable amount of the bitter content was removed. The area around the machine floor was also observed to be neat as the hopper height and collection basin geometry prevented spillovers and splashes. The machine reduced processing time and increased processing volume when compared to traditional hand processing. Also, the cost of operation and maintenance is minimised when compared to a motor-run machine. Further studies will be carried out on the techno-economic evaluation of the developed equipment to encourage market breakthroughs.

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Ethical issues: Not applicable.

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Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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